

**SEISMIC HAZARD ZONE REPORT FOR THE
BEVERLY HILLS 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

1998



DEPARTMENT OF CONSERVATION
Division of Mines and Geology

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR



DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

Copyright © 2001 by the California Department of Conservation. All rights reserved. No part of this publication may be reproduced without written consent of the Department of Conservation.

"The Department of Conservation makes no warranties as to the suitability of this product for any particular purpose."

SEISMIC HAZARD ZONE REPORT 023

**SEISMIC HAZARD ZONE REPORT FOR THE
BEVERLY HILLS 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

CALIFORNIA GEOLOGICAL SURVEY'S PUBLICATION SALES OFFICES:

Southern California Regional Office
888 South Figueroa Street, Suite 475
Los Angeles, CA 90017
(213) 239-0878

Publications and Information Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 445-5716

Bay Area Regional Office
345 Middlefield Road, MS 520
Menlo Park, CA 94025
(650) 688-6327

List of Revisions – Beverly Hills SHZR 023	
2001	Text updated
6/13/05	BPS address corrected, web links updated, Figure 3.5 added
10/10/05	Bay Area Regional Office and Southern California Regional Office addresses updated

CONTENTS

EXECUTIVE SUMMARY	vii
INTRODUCTION	1
SECTION 1 LIQUEFACTION EVALUATION REPORT Liquefaction Zones in the Beverly Hills 7.5-Minute Quadrangle, Los Angeles County, California	3
PURPOSE	3
BACKGROUND	4
METHODS SUMMARY	4
SCOPE AND LIMITATIONS	5
PART I	5
PHYSIOGRAPHY	5
GEOLOGY	6
ENGINEERING GEOLOGY	7
GROUND-WATER CONDITIONS	9
PART II	9
LIQUEFACTION POTENTIAL	9
LIQUEFACTION SUSCEPTIBILITY	10
LIQUEFACTION OPPORTUNITY	12
LIQUEFACTION ZONES	14
ACKNOWLEDGMENTS	15
REFERENCES	16

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT Earthquake-Induced Landslide Zones in the Beverly Hills 7.5-Minute Quadrangle, Los Angeles County, California	19
PURPOSE	19
BACKGROUND	20
METHODS SUMMARY	20
SCOPE AND LIMITATIONS.....	21
PART I	21
PHYSIOGRAPHY	21
GEOLOGY	23
ENGINEERING GEOLOGY	25
PART II.....	28
EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL.....	28
EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE	32
ACKNOWLEDGMENTS	34
REFERENCES	34
AIR PHOTOS	37
APPENDIX A Source of Rock Strength Data.....	38
SECTION 3 GROUND SHAKING EVALUATION REPORT Potential Ground Shaking in the Beverly Hills 7.5-Minute Quadrangle, Los Angeles County, California.....	39
PURPOSE	39
EARTHQUAKE HAZARD MODEL	40
APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS	44
USE AND LIMITATIONS.....	47
REFERENCES	48

ILLUSTRATIONS

Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station # 14 strong-motion record from the 17 January 1994 Northridge, California Earthquake.	30
Figure 3.1. Beverly Hills 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Firm rock conditions.	41
Figure 3.2. Beverly Hills 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Soft rock conditions.	42
Figure 3.3. Beverly Hills 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Alluvium conditions.	43
Figure 3.4. Beverly Hills 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration—Predominant earthquake.	45
Figure 3.5. Beverly Hills 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years magnitude-weighted pseudo-peak acceleration for alluvium - Liquefaction opportunity	46
Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Alluvium and Alluvial Fan Units, Beverly Hills Quadrangle.	11
Table 2.1. Summary of the Shear Strength Statistics for the Beverly Hills Quadrangle.	27
Table 2.2. Summary of the Shear Strength Groups for the Beverly Hills Quadrangle.	28
Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Beverly Hills Quadrangle.	32
Plate 1.1. Quaternary Geologic Map of the Beverly Hills Quadrangle.	50
Plate 1.2. Historically Highest Ground Water Contours and Borehole Log Data Locations, Beverly Hills Quadrangle.	51
Plate 2.1. Landslide Inventory, Shear Test Sample Locations, and Areas of Significant Grading, Beverly Hills Quadrangle.	52

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Beverly Hills 7.5-minute Quadrangle, Los Angeles County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

The Beverly Hills Quadrangle includes parts of the cities of Beverly Hills, Santa Monica, West Hollywood, Culver City, and Los Angeles and unincorporated areas of Los Angeles County. The University of California Los Angeles (UCLA) campus is located just north of the center of the quadrangle, near the community of Westwood, about 11 miles west of the Los Angeles Civic Center. The northern part of the quadrangle contains hilly and mountainous terrain of the southern slope of the Santa Monica Mountains, with local elevations greater than 1600 feet. The crest of the mountain range lies near the northern border of the quadrangle. The Santa Monica plain lies along the southern flank of the mountains. South of the plain are the Cheviot Hills which are separated from the Baldwin Hills by Ballona Creek. The Baldwin Hills are in the southeastern corner of the quadrangle. Most of the area south of the Santa Monica Mountains has been heavily urbanized.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

In the Beverly Hills Quadrangle the liquefaction zone extends from West Hollywood to the Ballona Creek floodplain along the eastern quadrangle boundary. The liquefaction zone is also located north of the Santa Monica Fault scarp in Westwood, in the lowlands in Venice, along the beaches and in the narrow canyon bottoms in the Santa Monica Mountains. The combination of dissected hillsides and weak rocks in the Santa Monica Mountains and the Baldwin Hills has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 20 percent of the Beverly Hills Quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet page: <http://www.conservation.ca.gov/CGS/index.htm>

Paper copies of Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Beverly Hills 7.5-minute Quadrangle.

SECTION 1

LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Beverly Hills 7.5-Minute Quadrangle, Los Angeles County, California

By
Mark J. De Lisle

**California Department of Conservation
Division of Mines and Geology**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Beverly Hills 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith,

1996). Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: <http://www.conservation.ca.gov/CGS/index.htm>

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Beverly Hills Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Construction of shallow ground-water maps showing the historically highest known ground-water levels
- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Beverly Hills Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Beverly Hills Quadrangle covers approximately 62 square miles in southwestern Los Angeles County. Portions of the cities of Beverly Hills, Santa Monica, West Hollywood, Culver City, and Los Angeles, as well as unincorporated areas of Los Angeles County, lie within the quadrangle. The University of California Los Angeles (UCLA) campus is located just north of the center of the quadrangle, near the Los Angeles community of Westwood, about 11 miles west of the Los Angeles Civic Center.

The northern part of the quadrangle is dominated by hilly and mountainous terrain of the southern slope of the eastern Santa Monica Mountains, which contain peaks greater than 1600 feet in elevation. The crest of the west-trending Santa Monica Mountain range lies near the northern border of the quadrangle. Numerous steep-sided, north-trending ridges extend from the crest to the coastal plain of the Los Angeles basin. An older dissected

alluvial surface, the Santa Monica plain of late Pleistocene age, lies along the southern flank of the Santa Monica Mountains. This surface, which was formed by several large coalescing alluvial fans, and has been dissected by erosion and the resultant channels filled with Holocene deposits.

Immediately south of the Santa Monica plain are the Cheviot Hills, an erosional surface extending westward from Beverly Hills into the southern part of the City of Santa Monica. Cheviot Hills and a western extension, the Ocean Park plain, are moderately dissected low rolling topography of late Pleistocene age. Along the present course of Ballona Creek, an ancestral west-flowing Los Angeles River dissected the southern side of the Cheviot Hills and the northern side of the Baldwin Hills forming Ballona Gap. Holocene alluvial materials have been deposited in the gap. The Baldwin Hills occupy the southeastern corner of the quadrangle and have been severely dissected, with relief of about 400 feet above Ballona Gap. The Baldwin Hills and Cheviot Hills represent the northernmost uplifts of the Newport-Inglewood structural zone.

For the most part, the area south of the Santa Monica Mountains has been heavily urbanized. The main drainage courses within the quadrangle are Ballona Creek, Santa Monica Canyon, Sepulveda Canyon, Dry Canyon, Stone Canyon, Brown Canyon (Beverly Glen), Benedict Canyon, Peavine Canyon, Higgins Canyon, Franklin Canyon and Coldwater Canyon.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. A compiled digital geologic map of the Beverly Hills Quadrangle was obtained from the U.S. Geological Survey (Yerkes, 1997). The contacts between bedrock and alluvium from the digital file were extensively modified to conform to the topographic contours of the USGS 7.5-minute quadrangle. Additional sources of geologic and engineering geology information used in this evaluation include Hoots (1930), Poland and others (1959), Castle (1960), Tinsley and Fumal (1985) and Dibblee (1991). Geologic maps show that rocks exposed in the Santa Monica Mountains are chiefly igneous, metamorphic, Cretaceous and Tertiary sedimentary rocks; whereas rocks exposed in the Baldwin Hills are dominantly marine deposits of Pleistocene age (for detailed descriptions of these units see Section 2 of this report). Surficial sediments mapped in the area consist of upper Pleistocene marine strata of sand, clay, gravel and conglomerate occupying two areas between Santa Monica Boulevard and Venice Boulevard and older Quaternary alluvial fan deposits forming the broad Santa Monica plain, which extends westward from the City of Beverly Hills. Young Quaternary alluvium has been deposited in the area of the City of Beverly Hills and within and adjacent to the Holocene drainage system. Along the shoreline are beach deposits, and adjacent to the beach, sand dunes are mapped locally. The generalized geology of the Beverly Hills Quadrangle is diagrammatically portrayed on Plate 1.1.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, several hundred borehole logs from the files of the California Department of Transportation (CalTrans), the California Regional Water Quality Control Board – Los Angeles Region, DMG Environmental Review and Hospital Review Projects and the U.S. Geological Survey. The USGS supplied copies of paper logs collected from the Los Angeles County Department of Public Works storm-drain investigations.

Borehole log selection was limited to boreholes drilled in canyons and areas underlain by Quaternary sedimentary deposits. Lithologic, soil test, and related data reported in the logs from about 200 boreholes were entered into the DMG geographic information system (GIS) database. The remaining logs were reviewed during this investigation to aid with the stratigraphic correlations. Locations of all exploratory boreholes entered into the database are shown on Plate 1.2.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Geotechnical and environmental borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area. Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized but give the most commonly encountered characteristics of the unit.

Older marine deposits (Qom?)

Older marine deposits make up much of the Cheviot Hills and the Ocean Park plain, underlying the area between Santa Monica Boulevard and Venice Boulevard. This material is medium dense to dense fine sand, silty sand, silt and clay with some gravel.

Older alluvium (Qoa)

Older alluvium in the Beverly Hills Quadrangle makes up the broad high Santa Monica plain along the south flank of the Santa Monica Mountains from Beverly Hills west to the

edge of the quadrangle. This material consists of alternating beds of medium dense to very dense sand, clay and silt. Gravel is abundant in many layers.

Eolian deposits (Qe?)

Eolian deposits mapped immediately inland from the modern beach are composed of a very thin layer of fine sand, less than 10 feet thick on borehole logs. This deposit is typically underlain by dense to very dense sand of older alluvial deposits.

Beach sand (Qm)

Onshore from Santa Monica Bay is a clean, well sorted, medium sand.

Younger alluvium (Qya, Qya1, Qya2)

The younger Quaternary alluvial deposits can be differentiated by their geomorphic relationships and have been mapped as Qya, Qya1 or Qya2. In the subsurface, based on the geotechnical parameters, it is not possible to distinguish among the generations on an alluvial fan. For liquefaction susceptibility these units are placed in the same group.

Borehole logs describe soil characteristics of alluvium fan deposits in the cities of Beverly Hills and West Hollywood area as alternating beds of clay, silt, and fine- to medium-grained sand. Gravel is abundant in many layers. Compactness of sand layers range from loose to moderately dense as indicated by both lithologic descriptions and penetration tests performed during drilling. The thickness of this unit in this area ranges from zero to more than 20 feet.

The Quaternary alluvial deposits in the area of Ballona Gap westward to Venice are also described as alternating beds of clay, silt, and fine- to medium-grained sand. Fine-grained material becomes more dominant and gravel is less abundant in this region. Compactness of sand layers ranges from loose to moderately dense. The thickness of this unit in this area ranges from zero to more than 25 feet. Locally, in the old Ballona channel, the thickness may be 50 feet or greater. Younger alluvium in the lowlands near Ballona Creek was subdivided into “alluvium” and “floodplain” deposits by Castle (1960). Both of these units have soft clay and silt near the surface but the “alluvium” was described by Castle as being a veneer over older deposits. The geology map used in this report depicts these as Qya2.

From Westwood south and west to the City of Santa Monica, young alluvial sediments deposited on erosional surfaces consist of alternating beds of clay, sandy clay, silt, sandy silt, fine sands, and, locally, scattered gravel. The fine sands are described as loose to slightly compact. Borehole logs indicate that total thickness of these deposits ranges from a few feet to about 45 feet.

The available data imply that the alluvium deposited in the canyons, as well as in the narrow channels incised in older Quaternary alluvium, consists predominately of loose to moderately dense, poorly sorted clayey sand, silty sand, with gravel.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the Beverly Hills Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the City of Beverly Hills Safety Element (Woodward-Clyde Consultants, 1987), compiled from geotechnical borehole logs, environmental monitoring wells and water-well logs, some dating back to the turn of the 20th century (Mendenhall, 1905). The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

The map was compared to other similar published maps as a check against any major discrepancies (Tinsley and others, 1985; Leighton and Associates, 1990). A depth to ground water map in the City of Santa Monica Safety Element (Leighton and others, 1994) shows water as shallow as 20 feet in the vicinity of Broadway Boulevard, Colorado Avenue, 26th Street, and Centinela Avenue. Several boreholes were examined in this area but no evidence was found for water this shallow.

Plate 1.2 shows that historical shallow water conditions (less than 40 feet depth) have existed in several areas of the Beverly Hills Quadrangle, namely from the West Hollywood area southwest to the eastern edge of Santa Monica, along the eastern and southern edges of the mapped area, and at the beach. Shallow water was encountered in boreholes in Santa Monica Canyon (just west, in the Topanga Quadrangle), and in Sepulveda, Benedict, Higgins, Franklin and Coldwater canyons.

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the

mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. This method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the State Mining and Geology Board (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. A qualitative susceptible soil inventory is outlined below and summarized in Table 1.1.

Older Marine Deposits (Qom?)

Older marine deposits generally have high blow counts. The materials are moderately dense to very dense fine sand and silty sand, stiff silt, and some clay. This unit is considered to have low liquefaction susceptibility.

Geologic Unit: Area	Sediment Type	Sand Consistency	Historic Depth to Ground Water	Liquefaction Susceptibility
Pre-Quaternary	Various			very low
Older marine (Qom?)	Sand, silty sand, silt and clay	Med. dense to dense	20 ft	low
Older alluvium (Qoa)	Sand, clay, silt with gravel	Med. dense to very dense	3 ft	low
Eolian (Qe)	Sand	Loose	17 ft	low (unsaturated)
Beach (Qm)	Sand	Loose	0 ft	high
Younger alluvium (Qya1, Qya2) Beverly Hills-West Hollywood	Clay, silt, sand, gravel	Loose to med. dense	5 ft	low to high
Younger alluvium (Qya1, Qya2) Ballona Gap and west	Clay, silt, sand	Loose to med. dense	10 ft	low to high
Younger alluvium (Qya1, Qya2) Westwood to Santa Monica	Clay, silt, sand	Loose to med. dense	20 ft	low to high
Younger alluvium (Qya1, Qya2, Qya) Canyon areas	Clayey sands, silty sand, gravel	Loose to med. dense	12 ft	high

Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Alluvium and Alluvial Fan Units, Beverly Hills Quadrangle.

Older Alluvial Fans

Based on the generally high blow counts recorded on the borehole logs, as well as the qualitative description of the materials as dense to very dense sands and silts, the older Quaternary alluvial fan deposits present in the Beverly Hills Quadrangle are considered to have low liquefaction susceptibility.

Eolian Deposits (Qe?)

Eolian deposits are very thin, less than 10 feet thick. These sediments are not saturated and, therefore, are considered to have low liquefaction susceptibility.

Beach Sand (Qm)

This loose sand is saturated and liquefied during the 1994 Northridge Earthquake (Stewart and others, 1994). The liquefaction susceptibility rating for this unit is high.

Younger Alluvium, Canyons and Incised Channels (Qya, Qya1, Qya2)

Canyon and incised channel deposits contain layers of sand and silty sand described as loose to moderately dense. Where the younger alluvium is underlain by pre-Quaternary bedrock water is reported in some boreholes within 15 feet of the ground surface. Blow count data from a few boreholes drilled through these sediments indicate that the shallow sands are loose to moderate dense. Accordingly, these deposits are assigned a high liquefaction susceptibility rating.

Younger Alluvium (Qya1, Qya2)

Borehole log information indicates that these deposits contain much clay, which does not liquefy, but also contain some silts and loose sandy soils. Thus, where the deposits are saturated the liquefaction susceptibility is rated as high and, if not saturated, rated as low.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in DMG's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Beverly Hills Quadrangle, peak accelerations of 0.45 g to 0.55 g, resulting from earthquakes ranging in magnitude from 6.4 to 7.0, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can

calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: $FS = (CRR / CSR) * MSF$. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

More than half of the 200 borehole logs collected for alluviated areas in the Beverly Hills Quadrangle (Plate 1.2) include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have

been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes
2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated
3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable
4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

- a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or
- b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or
- c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Beverly Hills Quadrangle is summarized below.

Areas of Past Liquefaction

Historic liquefaction has been reported (Stewart and others, 1994) in the beach deposits in Santa Monica (see Plate 1.2 for location) and these deposits are zoned as potentially liquefiable.

Artificial Fills

Non-engineered artificial fills have not been delineated or mapped in the Beverly Hills Quadrangle. Consequently, no areas are zoned for potential liquefaction relative to artificial fill.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that included penetration test data and reasonably sufficient lithologic descriptions were used to determine the liquefaction potential. Accordingly, these areas are zoned or not zoned according to the liquefaction potential based on adequate existing geotechnical data. Liquefaction analyses performed on data from a few boreholes drilled through younger alluvium of canyons and incised channel deposits indicate the shallow sands have factors of safety equal to or less than 1.0 for the anticipated earthquake shaking. In the younger alluvial deposits, most of the boreholes whose log data were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that liquefy under the given earthquake parameters. These areas containing saturated potentially liquefiable material are included in the zone.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in some canyon areas generally lack adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these cases are assumed to be similar to deposits where subsurface information is available. These canyon deposits, therefore, are included in the liquefaction zone for reasons presented in criterion 4-a above.

ACKNOWLEDGMENTS

The author thanks the staff of the California Department of Transportation (CalTrans), the Department of Water Resources; the Los Angeles County Department of Public Works; the California Regional Water Quality Control Board—Los Angeles Region; and John Tinsley of the USGS for their assistance in the collection of borehole data. Special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their GIS operations support, and for designing and plotting the graphic displays associated with the liquefaction zone map and this report.

REFERENCES

- American Society for Testing and Materials, 1999, Standard test method for penetration test and split-barrel sampling of soils, Test Method D1586-99, *in* Annual Book of ASTM Standards, v. 4.08.
- Budiman, J.S. and Mohammadi, Jamshid, 1995, Effect of large inclusions on liquefaction of sands, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 48-63.
- California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California, Special Publication 117, 74 p.
- California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones in California, Special Publication 118, 12 p.
- Castle, R.O., 1960, Surficial geology of the Beverly Hills and Venice quadrangles, California: U.S. Geological Survey Open File Report, scale 1:24,000.
- Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.
- Dibblee, T.W., Jr., 1991, Geologic map of the Beverly Hills and Van Nuys (South 1/2) quadrangles, Los Angeles County, California: Dibblee Geological Foundation Map DF-31, Santa Barbara California, scale 1:24,000.
- Evans, M.D. and Zhou, Shengping, 1995, Liquefaction behaviour of sand-gravel composites: American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 121, no. 3, p. 287-298.
- Harder, L.F. and Seed, H.B., 1986, Determination of penetration resistance for coarse-grained soils using the Becker hammer drill: University of California at Berkeley, College of Engineering, Earthquake Engineering Research Center, report no. UCB/EERC-86/06, 126 p.
- Hoots, H.H., 1930, Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California: U.S. Geological Survey Professional Paper 165-C, 134 p.
- Ishihara, Kenji, 1985, Stability of natural deposits during earthquakes, *in* Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, v.1, p. 321-376.

- Leighton and Associates, Inc., 1990, Hazard reduction in Los Angeles County: Technical Appendix to the Safety Element of the Los Angeles County General Plan, Department of Regional Planning, County of Los Angeles, 2 v.
- Leighton and Associates, Inc., with Topping, K.C., 1994, Safety Element for the City of Santa Monica General Plan: Project No. 7910399-01.
- Mendenhall, W.C., 1905, Development of underground waters in the western coastal plain region of southern California: U.S. Geological Survey Water-Supply and Irrigation Paper No. 139, 105 p.
- National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.
- Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, Tianqing, Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open File Report 96-08; U.S. Geological Survey Open File Report 96-706, 33 p.
- Poland, J.F., Garrett, A.A. and Sinnott, Allen, 1959, Geology, hydrology, and chemical character of ground waters in the Torrance-Santa Monica area, California: U.S. Geological Survey Water-Supply Paper 1461, 425 p.
- Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.
- Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.
- Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.
- Seed, H.B., Tokimatsu, Kohji, Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.
- Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.
- Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

- Stewart, J.P., Bray, J.D., Seed, R.B. and Sitar, N., 1994, Preliminary report on the principal geotechnical aspects of the January 17, 1994 Northridge earthquake: Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, Report No. UCB/EERC-94/08.
- Sy, Alex, Campanella, R.G. and Stewart, R.A., 1995, BPT-SPT correlations for evaluations of liquefaction resistance in gravelly soils, *in* Evans, M.D. and Frigaszy, R.J., *editors*, Static and Dynamic Properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 1-19.
- Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles Region—An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-125.
- Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region — An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.
- Woodward-Clyde Consultants, 1987, Geotechnical report—Seismic safety element for the City of Beverly Hills, California: Project No. 42152A.
- Yerkes, R.F., 1997, Preliminary geologic map of the Beverly Hills Quadrangle, southern California: U.S. Geological Survey Open File Report 97-256, scale 1:24,000.
- Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.
- Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.
- Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.
- Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Beverly Hills 7.5-Minute Quadrangle, Los Angeles County, California

By

Michael A. Silva and Pamela J. Irvine

**California Department of Conservation
Division of Mines and Geology**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Beverly Hills 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic

hazard zone mapping in California can be accessed on DMG's Internet web page:
<http://www.conservation.ca.gov/CGS/index.htm>.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Beverly Hills Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area
- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared
- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area
- Seismological data in the form of DMG probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard

potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Beverly Hills Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Beverly Hills Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Beverly Hills Quadrangle covers approximately 62 square miles in southwestern Los Angeles County. Portions of the cities of Beverly Hills, Santa Monica, West Hollywood, Culver City, and Los Angeles, as well as unincorporated areas of Los Angeles County, lie within the quadrangle. The University of California Los Angeles (UCLA) campus is

located just north of the center of the quadrangle, near the Los Angeles community of Westwood, about 11 miles west of the Los Angeles Civic Center.

The northern part of the quadrangle is dominated by hilly and mountainous terrain of the southern slope of the eastern Santa Monica Mountains, which contain peaks greater than 1600 feet in elevation. The crest of the west-trending Santa Monica Mountain range lies near the northern border of the quadrangle. Numerous steep-sided, north-trending ridges extend from the crest to the coastal plain of the Los Angeles basin. An older dissected alluvial surface, the Santa Monica plain, lies along the southern flank of the Santa Monica Mountains. This surface, which was formed by several large coalescing alluvial fans, has been eroded by streams draining the Santa Monica Mountains and backfilled with younger alluvium. Younger alluvial fans, which form part of the Hollywood piedmont slope, have been deposited on the older alluvial plain in the eastern part of the quadrangle.

The Baldwin Hills and Cheviot Hills extend from the southeast corner of the map toward Beverly Hills and represent the northernmost domal uplifts of the Newport-Inglewood structural zone. In the map area, the north slope of the Baldwin Hills rises more than 400 feet above sea level and has been deeply incised by erosion. The Cheviot Hills are characterized by moderately dissected, low rolling topography. In the southwest corner of the quadrangle, a slightly dissected older marine plain, the Ocean Park plain, extends from the ocean inland in the southern part of the City of Santa Monica and is believed to be a westward extension of the Cheviot Hills. Ballona Creek flows through Ballona Gap, which was formed by downwarping and subsequent erosion by local drainages and the ancestral Los Angeles River, between the Baldwin Hills and Cheviot Hills and continues along the southern edge of the Ocean Park plain, eventually exiting into Santa Monica Bay in the Venice Quadrangle.

Access to the Santa Monica Mountains is provided by numerous narrow residential streets, broader boulevards, and fire roads that follow north-trending canyons or ridgecrests between Sunset Boulevard on the south and Mulholland Drive, which follows the crest of the Santa Monica Mountains, on the north. The Santa Monica Freeway (I-10) traverses the area from west to east and the San Diego Freeway (I-405) cuts diagonally from southeast to northwest through the quadrangle.

Residential and commercial development is concentrated in the area south of the Santa Monica Mountains. Hillside residential development began in the 1920's and 1930's, grew rapidly after World War II, and continues with several mass-grading projects today. Other current land uses include: parklands, sanitary landfills, oil fields, golf courses, and reservoirs, including Stone Canyon Reservoir and Franklin Canyon Reservoir.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Beverly Hills Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological

Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1964 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To update the terrain data to reflect areas that have recently undergone large-scale grading, graded areas in the hilly portions of the Beverly Hills Quadrangle, essentially the Santa Monica Mountains, were identified. Terrain data for these areas were obtained from an airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's Jet Propulsion Laboratory (JPL), and processed by Calgis, Inc. (GeoSAR Consortium, 1995; 1996). These terrain data were also smoothed and filtered prior to analysis. Plate 2.1 shows those areas where the topography is updated to 1994 grading conditions.

A slope map was made from both the USGS DEM and the radar DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

A recently compiled U.S. Geological Survey (USGS) geologic map was obtained in digital form (Yerkes, 1997) for the Beverly Hills Quadrangle. The contacts between bedrock and alluvium from the digital file were extensively modified to conform to the topographic contours of the USGS 7.5-minute quadrangle. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. Bedrock geology was also modified to reflect more recent mapping. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The oldest geologic unit mapped in the Beverly Hills Quadrangle is the Jurassic Santa Monica Slate, which is widely exposed in the northern part of the quadrangle where it forms rugged slopes in the Santa Monica Mountains. Locally, it consists of intensely jointed and fractured slate (Jsm) and phyllite (Jsp) with well-developed slaty cleavage and a thick weathered zone characterized by angular chips and thin slabs of slate surrounded by clay. The spotted slate (Jsms) contains abundant crystals of cordierite believed to have formed as a result of contact metamorphism of the Santa Monica Slate with granitic intrusions. Cretaceous granodioritic and quartz dioritic (Kgr) plutonic rocks are exposed in the northeast corner of the quadrangle where they form an irregular intrusive contact with the slate characterized by inclusions of slate and schist in the granite and numerous veins of quartz. Locally, at the surface, the granitic rocks are soft and crumbly due to weathering. Because of the fractured and deeply weathered nature of

the slate and granitic rocks, they are prone to landslides and debris flows on moderate to steep slopes.

In the map area, Santa Monica Slate and Cretaceous granite are overlain unconformably by deep-marine clastic sedimentary rocks of the Cretaceous Tuna Canyon Formation (Kt), which consists of interbedded sandstone, siltstone, and pebble-cobble conglomerate. Overlying the Tuna Canyon Formation are the Paleocene and Eocene nonmarine clastic sedimentary rocks of the Simi Conglomerate and Las Virgenes Sandstone and marine fine-grained sandstones of the Santa Susana Formation (Colburn and Novak, 1989). Because of the map scale, all of the Paleocene and Eocene rocks are included in the Santa Susana Formation (Tss; Coal Canyon Formation of Yerkes and Campbell, 1979).

Other Tertiary bedrock formations include the shallow-marine clastic sedimentary rocks and volcanics of the middle Miocene Topanga Group and deep-marine biogenic and clastic rocks of the upper Miocene Modelo Formation. The Topanga Group consists of interbedded conglomerate, massive sandstone, concretionary shale and siltstone (Tt, undivided), and basalt flows (Tb). The Modelo Formation is composed of interbedded clay shale, siltstone, and sandstone (Tm) and massive, fine- to coarse-grained sandstone (Tms). These formations are prone to slope failure where bedding planes are inclined in the same direction as the slope.

The Benedict Canyon fault zone cuts diagonally through the eastern Santa Monica Mountains in a northeasterly direction. Bedrock along this zone is more susceptible to slope failure because it has been highly fractured and, in some areas, experiences increased pore pressures due to the impounding of ground water along the fault (Denison, 1994).

The Baldwin Hills are primarily composed of marine sediments of Pleistocene age. Stratigraphic correlation of Plio-Pleistocene and Quaternary strata within the Los Angeles basin is difficult because of rapid lateral facies changes resulting from fluctuations in the paleo-shoreline and the time-transgressive nature of the faunal assemblages (Quinn and others, 1997). Because of the current lack of well-defined Quaternary correlations and nomenclature, the formation designations used in this study for the Baldwin Hills area should be regarded as generalized and informal.

The oldest Quaternary unit mapped in the Beverly Hills Quadrangle is the lower Pleistocene Inglewood Formation (Qi; "A" formation of Castle, 1960a and 1960b), which is exposed on the northern slope of the Baldwin Hills. It is composed of thinly interbedded siltstone and fine sandstone deposited in a shallow marine environment. Unconformably overlying the Inglewood Formation, is the Pleistocene San Pedro Formation (Qsp; "B" formation of Castle, 1960a and 1960b), which consists of poorly consolidated, fine- to coarse-grained sand interbedded with thin beds and lenses of gravel deposited in a near-shore marine environment ("Qc" in Weber and others, 1982). Also included in this unit are fluvial sand and gravel with local beds of clayey silt ("Qb" in Weber and others, 1982). A reddish brown, well-cemented and resistant, locally pebbly or gravelly, silty sand caps some of the ridges in the southeast corner of the map and is

designated older alluvium (Qoa; “Qf” in Weber and others, 1982; “cap deposits” in Castle, 1960a and 1960b).

Quaternary sediments covering the remainder of the Beverly Hills Quadrangle include older marine deposits (Qom) with interfingering continental sediments on the Ocean Park Plain and Cheviot Hills, older and younger alluvial-fan deposits at the margins of the Santa Monica Mountains and Baldwin Hills (Qof, Qoa, and Qya1), floodplain and stream deposits in the basin and the canyons (Qya1, Qya2, Qya), eolian deposits (Qe), and beach sand (Qm). Landslides (Qls and Qls?) are widespread in the Beverly Hills Quadrangle, occurring on steep slopes in the Santa Monica Mountains and the northern slope of the Baldwin Hills. Modern man-made (artificial) fills (af) are also mapped in some areas. A more detailed discussion of the Quaternary deposits in the Beverly Hills Quadrangle can be found in Section 1.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Beverly Hills Quadrangle was prepared (Irvine, unpublished) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. The following aerial photos were used (see Air Photos in References) for landslide interpretation: Fairchild (1927), Fairchild (1928), NASA (1994), and USDA (1952/53). Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Byer, 1987; Dibblee, 1991; Harp and Jibson, 1995; L.A. Dept. of Public Works, 1963; Sabins and others, 1992; Stone & Associates, 1973; CDWR, 1961; Cobarrubias, 1992; Hoots, 1930; Poland and others, 1959; Weber and others, 1982; and Weber and others, 1979). Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Beverly Hills Quadrangle geologic map were obtained from the City of Los Angeles, Department of Building and Safety

(see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average ϕ) and lithologic character. Average (mean and median) ϕ values for each geologic map unit and corresponding strength group are summarized in Table 2.1. If no shear test data were available from adjacent quadrangles, geologic units were added to existing strength groups on the basis of lithologic and stratigraphic similarities. Within the Beverly Hills Quadrangle, no shear tests were available for Tss, Qi, Qsp, af and all Quaternary alluvial units except for Qa. Shear test data for Qi and Qsp from the Venice and Hollywood quadrangles were used to assign these units to existing strength groups. The other units were added to existing groups on the basis of lithologic and stratigraphic similarities.

For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

For the Beverly Hills geologic rock strength map, geologic formations within 100 feet of the Benedict Canyon Fault were judged to be altered by fault processes and were assigned to a rock strength category that is one level lower than non-faulted units.

The results of the grouping of geologic materials in the Beverly Hills Quadrangle are in Tables 2.1 and 2.2.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The formations, which contain interbedded sandstone and shale, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation,

which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the formations are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

BEVERLY HILLS QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	Number Tests	Mean/Median Phi	Mean/Median (Group phi) (deg)	Group Mean/Median C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Kgr	39	37.8/38	35.6/36	659/475	Tb	35.6
	Jsp	18	36.5/37				
	TK	4	35.9/35.7				
	Jsms	39	35/36				
	Jms	37	34.2/34				
GROUP 2	Tms(fbc)	15	33.2/34	32.7/33	548/400	Tss	32.7
	Tt(fbc)	43	33/33				
	Kt	48	32.4/33				
	Tm(fbc)	17	32.3/34				
GROUP 3	Qa	3	31.7/32	30.3/31.5	660/550	af, Qal, Qao, Qay1, Qay2, Qe?, Qi, Qm, Qoa, Qom?, Qt	30.3
	Tm(abc)	15	30.1/31				
GROUP 4	Tms(abc)	5	28/29	27/28	712/600		27
	Tt(abc)	16	26.8/27.5				
GROUP 5	Qls						12

abc = adverse bedding condition, fine-grained material strength

fbc = favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the Shear Strength Statistics for the Beverly Hills Quadrangle.

SHEAR STRENGTH GROUPS FOR THE BEVERLY HILLS QUADRANGLE				
GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Kgr Jsm Jsms Jsp Tb TK	Kt Tm(fbc) Tms(fbc) Tss Tt(fbc)	Af Aq Qal Qay1,2 Qe? Qi Qm Qoa Qom? Qt Tm(abc)	Qsp Qya1 Qya2 Tms(abc) Tt(abc)	Qls

Table 2.2. Summary of the Shear Strength Groups for the Beverly Hills Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity.” For the Beverly Hills Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.4 to 7.1
Modal Distance:	2.5 to 7.4 km
PGA:	0.46 to 0.55g

The strong-motion record selected for the slope stability analysis in the Beverly Hills Quadrangle was the Channel 3 (N35°E horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge Earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Beverly Hills Quadrangle.

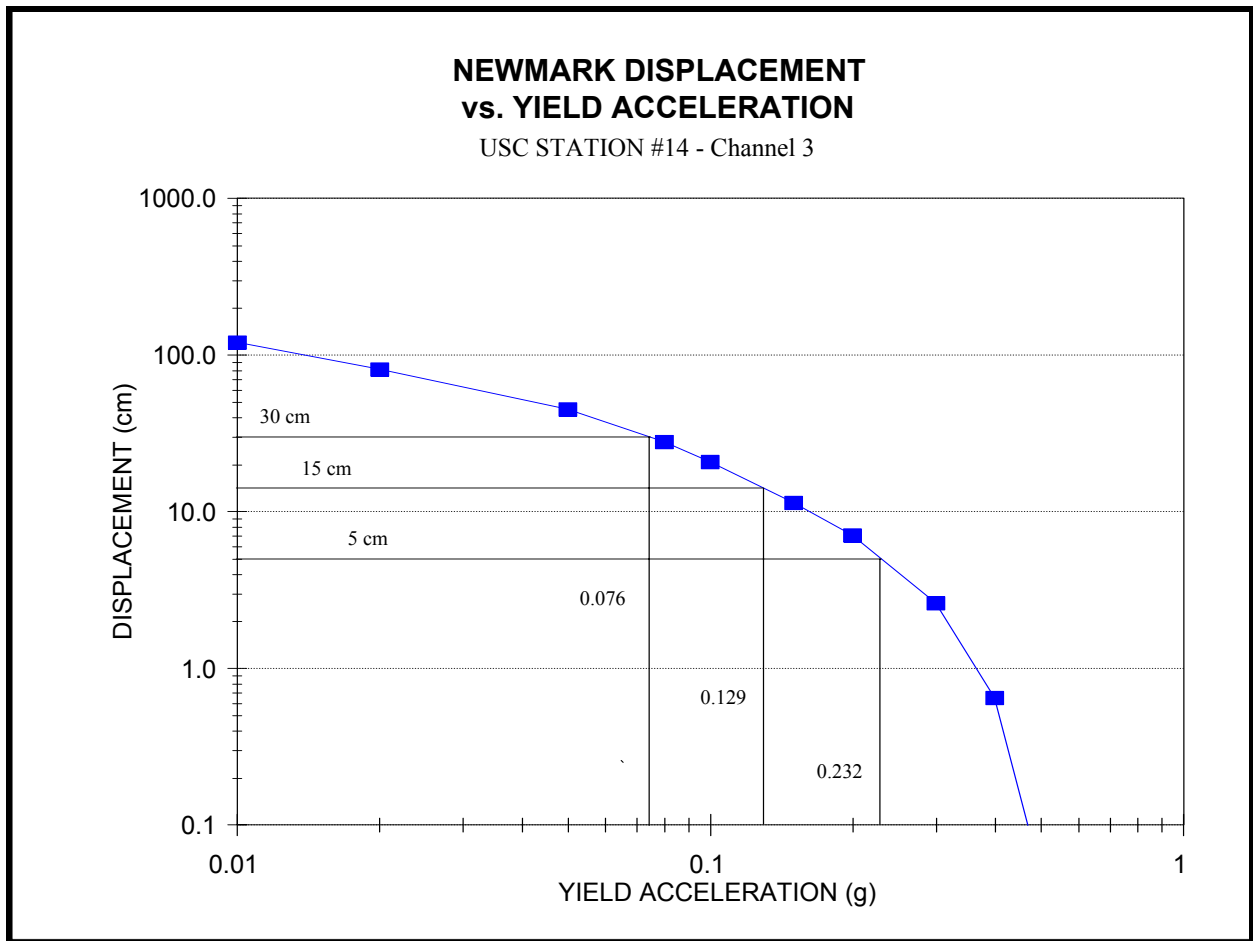


Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station # 14 strong-motion record from the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.076g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)
2. If the calculated yield acceleration fell between 0.076g and 0.129g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)
3. If the calculated yield acceleration fell between 0.129g and 0.232g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)
4. If the calculated yield acceleration was greater than 0.232g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

BEVERLY HILLS QUADRANGLE HAZARD POTENTIAL MATRIX												
		SLOPE CATEGORY										
Geologic Material Group	Mean Phi	I 0-14	II 14-19	III 19-29	IV 29-34	V 34-38	VI 38-44	VII 44-47	VIII 47-50	IX 50-58	X 58-64	XI >64
1	35.7	VL	VL	VL	VL	VL	VL	VL	L	L	M	H
2	32.7	VL	VL	VL	VL	VL	L	L	L	M	H	H
3	30.3	VL	VL	VL	VL	L	L	M	M	H	H	H
4	27	VL	VL	VL	L	L	M	H	H	H	H	H
5	12	L	M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Beverly Hills Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

No earthquake-triggered landslides had been identified in the Beverly Hills Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a few small, shallow slope failures in the Beverly Hills Quadrangle (Harp and Jibson, 1995). Landslides attributed to the Northridge earthquake covered approximately 8 acres of land in the quadrangle. Of these landslides, 89% fall within the area of the hazard zone, based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by DMG (McCrink and Real, 1996), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 4 is included for all slopes steeper than 29 percent.
3. Geologic Strength Group 3 is included for all slopes steeper than 34 percent.
4. Geologic Strength Group 2 is included for all slopes steeper than 38 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 47 percent.

This results in approximately 20 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Beverly Hills Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the City of Los Angeles with the assistance of Nicki Girmay. Robert Hancock and Tony Brown (City of Los Angeles Bureau of Engineering) provided helpful observations of historic slope failures in the Santa Monica Mountains. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Barbara Wanish, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the hazard zone map and this report. Assistance in the application of the radar DEM was provided by Rick Wilson and Tim McCrink.

REFERENCES

- Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.
- Byer, J.W., 1987, Legends of the Santa Monica Mountains, *in* Cugno, G. and Irvine, J., *compilers*, Selected landslides and stabilization projects of the Santa Monica Mountains, Los Angeles, California: Association of Engineering Geologists Southern California Section, 1987 Annual Field Trip Guidebook, p. 2-10.
- California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.
- California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 12 p.
- California Department of Water Resources, 1961, Planned utilization of the ground water basins of the coastal plain of Los Angeles, Appendix A, Ground water geology: California Department of Water Resources Bulletin 104, 181 p.
- Castle, R.O., 1960 a, Geologic map of the Baldwin Hills area, California: U.S. Geological Survey Open-File Report, scale 1:12,000.

- Castle, R.O., 1960 b, Surficial geology of the Beverly Hills and Venice quadrangles, California: U.S. Geological Survey Open-File Report, scale 1:24,000.
- Cobarrubias, J.W., 1992, The Mission Canyon landfills, *in* Ehlig, P.L. and Steiner, E.A., *compilers*, Engineering geology field trips—Orange County, Santa Monica Mountains, and Malibu: Southern California Section Association of Engineering Geologists, Guidebook and Volume for the 35th Annual Meeting of the Association of Engineering Geologists, p. B68-B72.
- Colburn, I.P. and Novak, G.A., 1989, Paleocene conglomerates of the Santa Monica Mountains, California, petrology, stratigraphy, and environments of deposition *in* Colburn, I.P., Abbott, P.L. and Minch, J.A., *editors*, Conglomerates in basin analysis—A symposium dedicated to A.O. Woodford: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 227-253.
- Denison, F.E., 1994, Landslides, debris flows, and groundwater along the Benedict Canyon fault zone, eastern Santa Monica Mountains, related to the 1992-1993 winter storms, City of Los Angeles, California: Geological Society of America Abstracts with Programs, Cordilleran Section Annual Meeting, v. 26, no. 2., p. 48.
- Dibblee, T.W., Jr., 1991, Geologic map of the Beverly Hills and Van Nuys (south 1/2) quadrangles, Los Angeles County, California: Dibblee Geological Foundation Map #DF-31, scale 1:24,000.
- GeoSAR Consortium, 1995, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B335/00, 135 p.
- GeoSAR Consortium, 1996, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B378/00, 70 p.
- Harp, E.L. and Jibson, R.W., 1995, Inventory of landslides triggered by the 1994 Northridge, California earthquake: U.S. Geological Survey Open-File Report 95-213, 17 p.; Plate 1, scale 1:100,00; Plate 2, scale 1:50,000.
- Hoots, H.W., 1930, Geology of the eastern part of the Santa Monica Mountains, City of Los Angeles, California: U.S. Geological Survey Professional Paper 165-C, 134 p., scale 1:24,000.
- Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.
- Irvine, P.J., unpublished, Landslide inventory of the Beverly Hills 7.5' Quadrangle, Los Angeles County, California.

- Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.
- Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.
- Los Angeles Department of Public Works, 1963, Preliminary geologic maps of the Santa Monica Mountains, City of Los Angeles, California: 312 p., scale 1:4,800.
- McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.
- Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.
- Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open File Report 96-08; U.S. Geological Survey Open File Report 96-706, 33 p.
- Poland, J.E., Garrett, A.A. and Sinnott, A., 1959, Geology, hydrology, and chemical character of ground waters in the Torrance-Santa Monica area, California: U.S. Geological Survey Water Supply Paper 1461, 425 p.; Plate 1, north half, map scale 1:31680.
- Quinn, J.P., Ponti, D.J., Hillhouse, J.W. and Powell, C.L. II, 1997, Quaternary chronostratigraphic constraints on deformation and blind thrust faulting, northern Los Angeles basin: Final Technical Report 1434-95-G-2523 to the U.S. Geological Survey.
- Sabins, E.H., Rapp, L.R. and Heron, C.W., 1992, Engineering geology of the Getty Center, Brentwood, California, in Ehlig, P.L. and Steiner, E.A., *compilers*, Engineering geology field trips—Orange County, Santa Monica Mountains, and Malibu: Southern California Section, Association of Engineering Geologists, Guidebook and Volume for the 35th Annual Meeting of the Association of Engineering Geologists, p. B74-86.
- Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

- Stone, Robert & Associates, 1973, Geologic and soils engineering factors—Mission Canyon landfill, Consultant Report—Job No. 1-2-0150-95, *in* Mission Canyon Landfill Draft EIR, p. 364-439.
- Trifunac, M.D., Todorovska, M.I. and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: *Soil Dynamic and Earthquake Engineering*, v. 13, no. 3, p. 187-196.
- U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.
- Weber, F.H., Jr., Treiman, J.A., Tan, S.S. and Miller, R.V., 1979, Landslides in the Los Angeles region, California: effects of the February-March rains: California Division of Mines and Geology Open-File Report 79-4, 277 p., scale 1:250,000.
- Weber, F.H., Jr., ed., Hsu, E.Y., Saul, R.B., Tan, S.S. and Treiman, J.A., 1982, Slope stability and geology of the Baldwin Hills, Los Angeles, California: California Division of Mines and Geology Special Report 152, 93 p., Plate 1, scale 1:4,800.
- Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: *Bulletin of the Seismological Society of America*, v. 73, p. 863-877.
- Yerkes, R.F., 1997, Preliminary geologic map of the Beverly Hills 7.5' Quadrangle, southern California: U.S. Geological Survey Open File Report 97-256, scale 1:24,000.
- Yerkes, R.F. and Campbell, R.H., 1979, Stratigraphic nomenclature of the central Santa Monica Mountains, Los Angeles County, California: U.S. Geological Survey Bulletin 1457-E, 31 p.
- Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

- Fairchild Aerial Surveys, 1927, Aerial photography, Flight 113, Frames 21-29, 33-41, 47-60, 71-79, 119-131, black and white, vertical, scale 1:19,000.
- Fairchild Aerial Surveys, 1928, Aerial photography, Flight C300, Frames J248-250, J253-257, K19-25, K44-50, black and white, vertical, scale 1:19,000.

NASA (National Aeronautics and Space Administration), 1994, Aerial photography, 04688, Flight 94-002-01, January 21, 1994, Frames 69-72, 73-79, 146-149, 155-164, 210-219, 234-244, black and white, vertical, scale 1:15,000.

USDA (U.S. Department of Agriculture), 1952/53, Aerial photography, Flight AXJ, Frames 3K 129-137, 4K 148-150, 14K 57-62, black and white, vertical, scale 1:20,000.

APPENDIX A SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Building and Safety	299

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Beverly Hills 7.5-Minute Quadrangle, Los Angeles County, California

By

**Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros,
Charles R. Real, and Michael S. Reichle**

**California Department of Conservation
Division of Mines and Geology**

***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided

herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions *for the analysis of ground failure* according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage:

<http://www.conservation.ca.gov/CGS/index.htm>

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

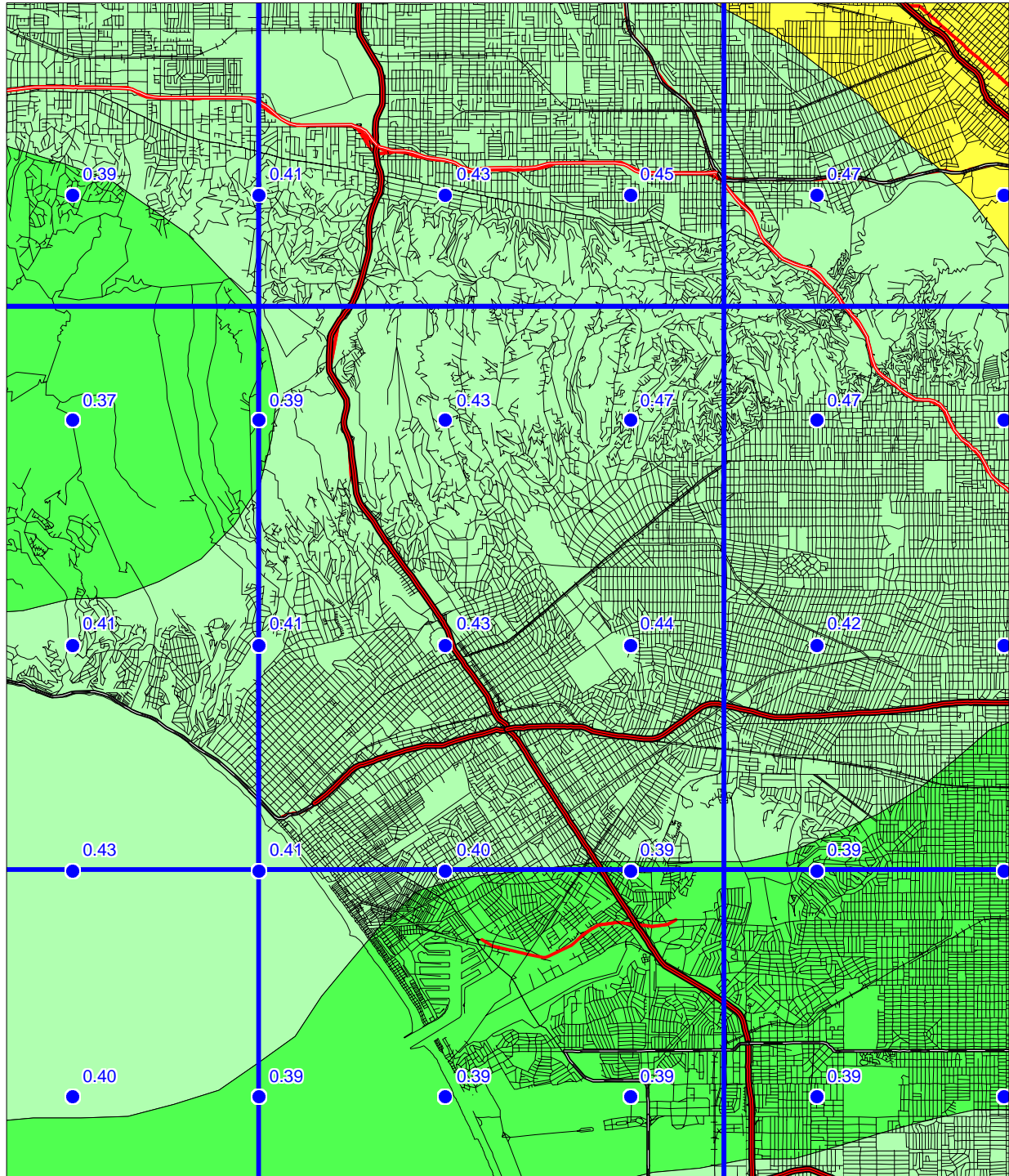
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

BEVERLY HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology



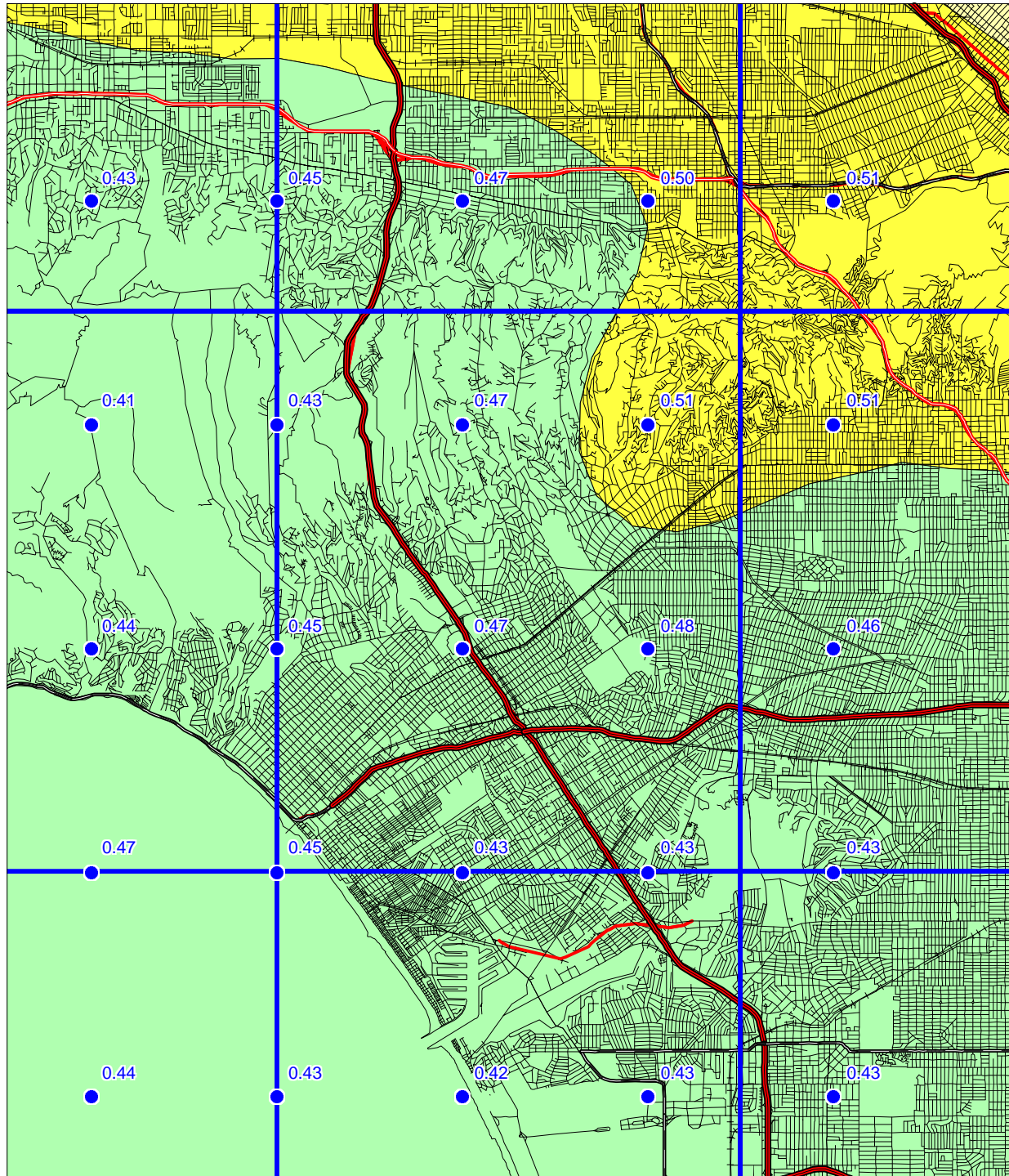
Figure 3.1

BEVERLY HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology



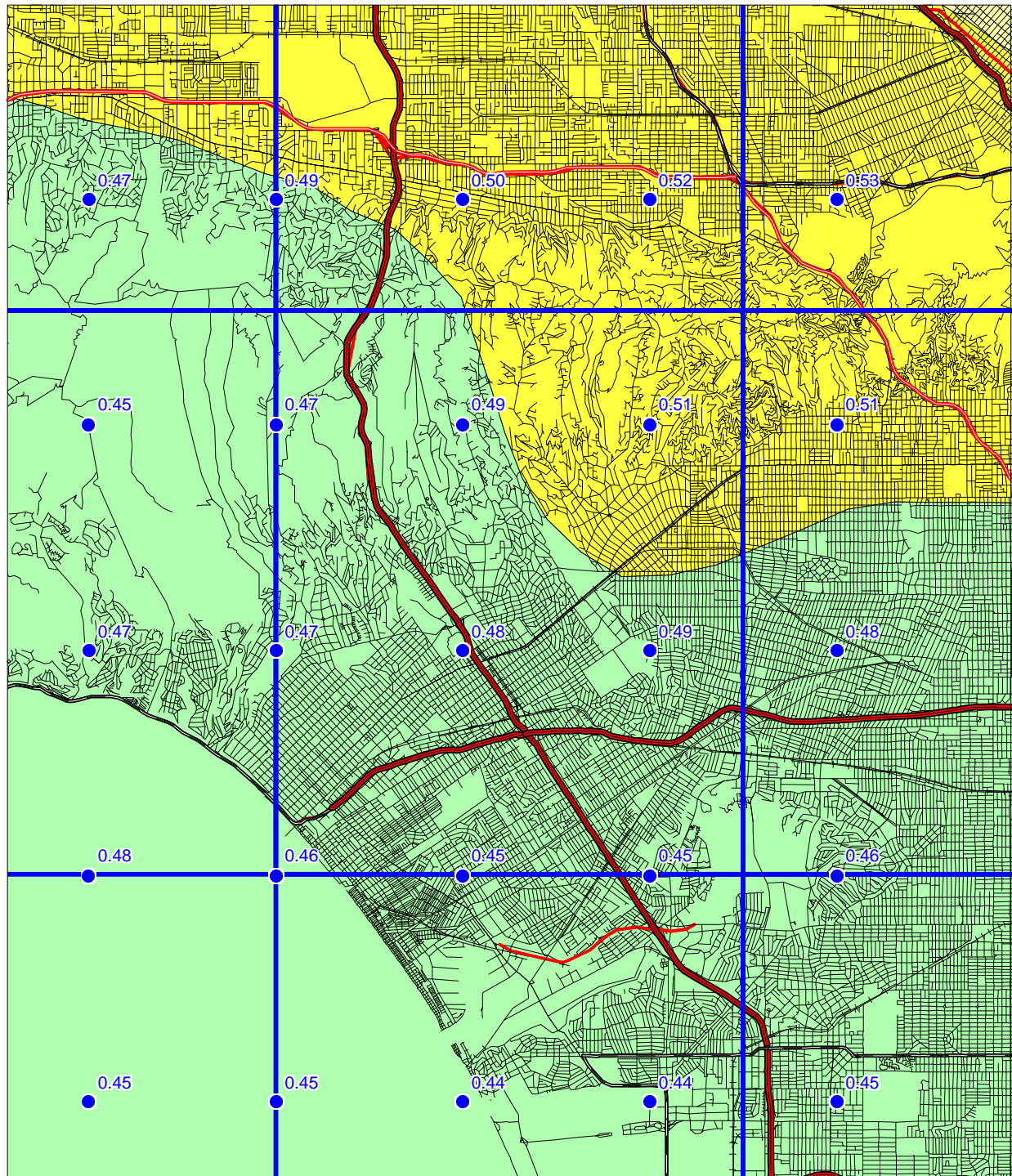
Figure 3.2

BEVERLY HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3



quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

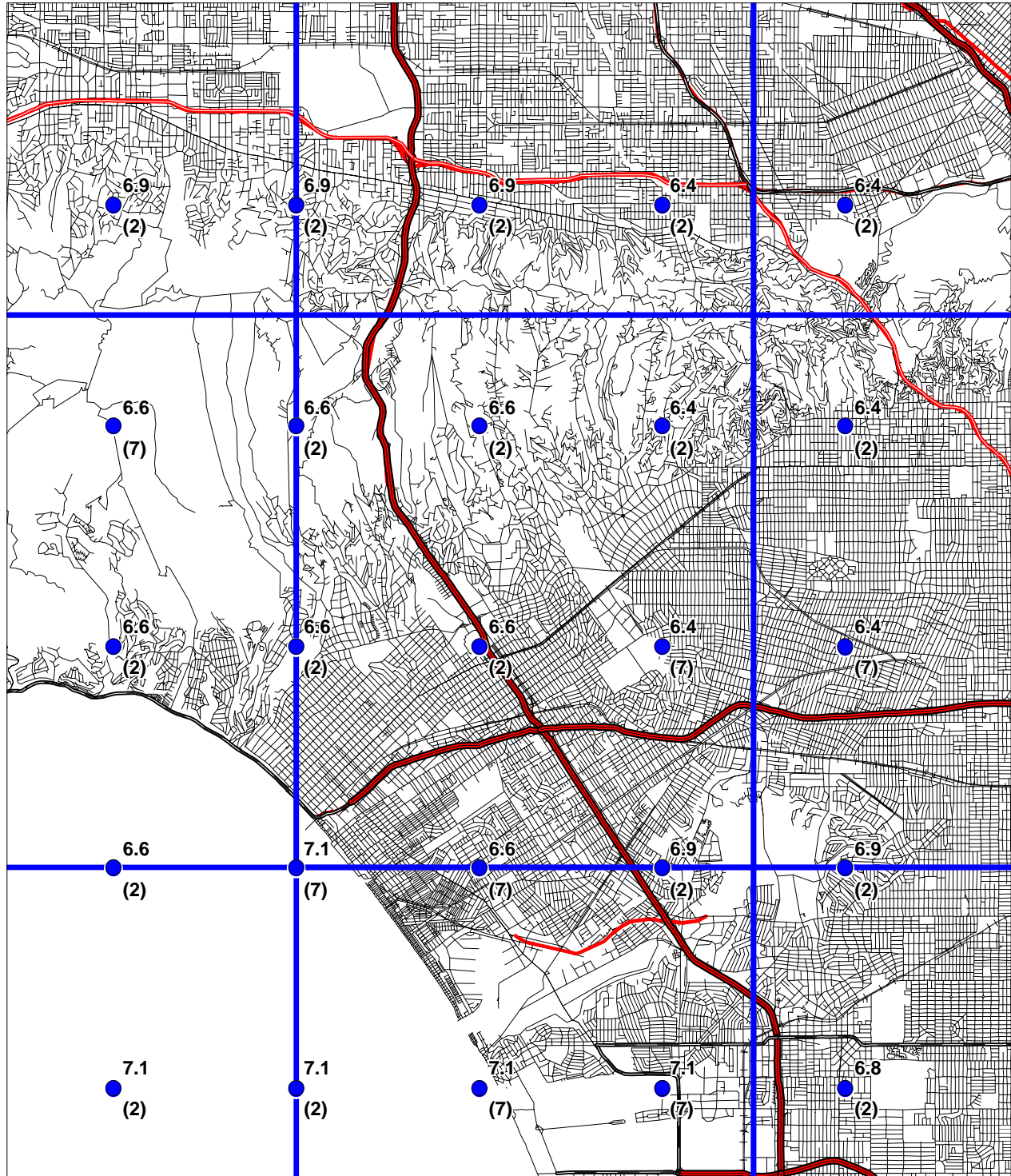
SEISMIC HAZARD EVALUATION OF THE BEVERLY HILLS QUADRANGLE
BEVERLY HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.4

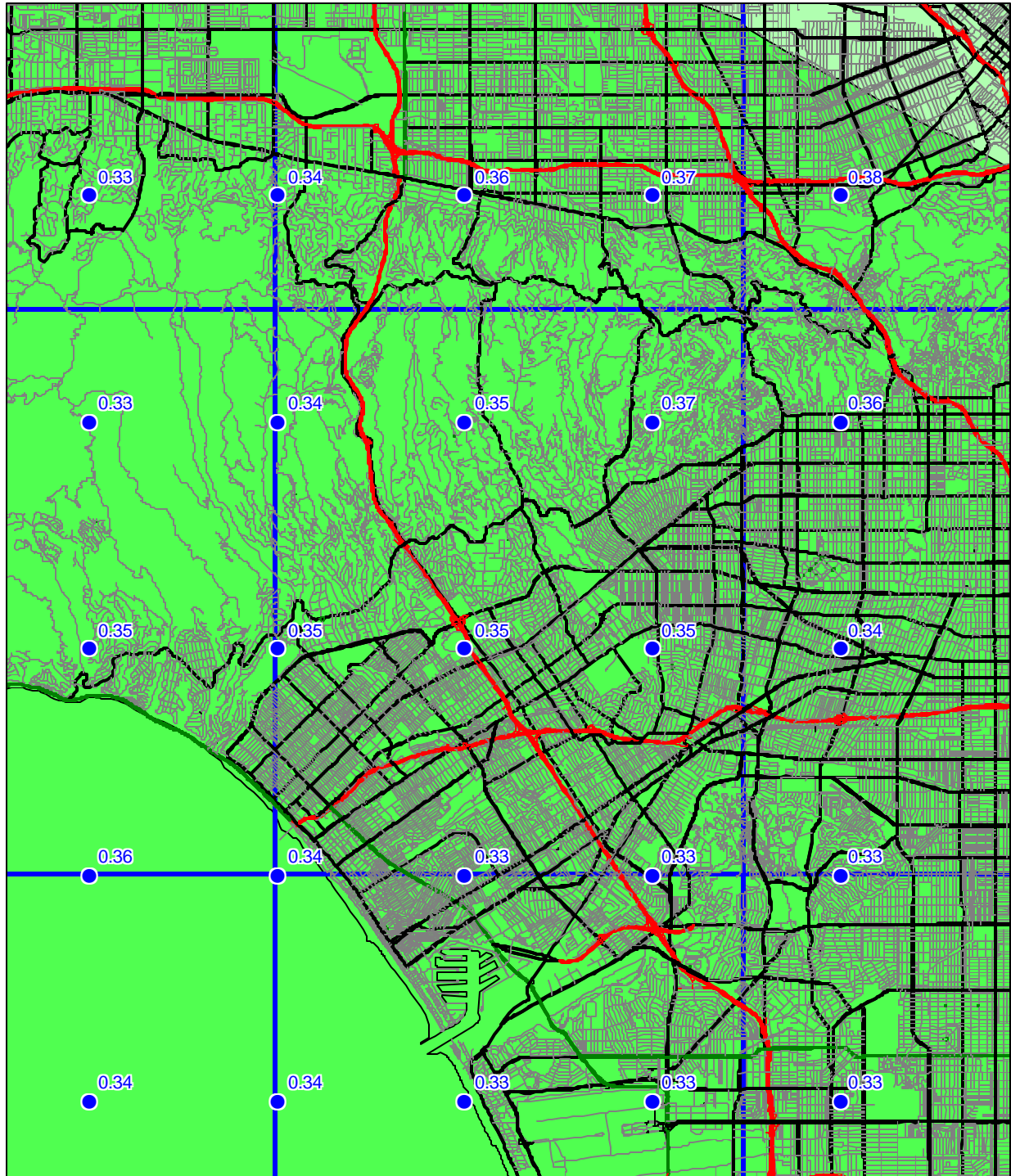


SEISMIC HAZARD EVALUATION OF THE BEVERLY HILLS QUADRANGLE
BEVERLY HILLS 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey



Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.
2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours.*
3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).
4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.
5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the

recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

- Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: *Seismological Research Letters*, v. 68, p. 154-179.
- California Department of Conservation, Division of Mines and Geology, 1997, *Guidelines for evaluating and mitigating seismic hazards in California: Special Publication 117*, 74 p.
- Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: *Seismological Research Letters*, v. 68, p. 180-189.
- Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: *Bulletin of the Seismological Society of America*, v. 85, no. 5, p. 1645-1649.
- Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: *Bulletin of the Seismological Society of America*, v. 86, p. 1681-1691.
- International Conference of Building Officials (ICBO), 1997, *Uniform Building Code: v. 2, Structural engineering and installation standards*, 492 p.
- Jennings, C.W., *compiler*, 1994, *Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.*
- Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

- Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.
- Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.
- Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.
- Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.
- Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.

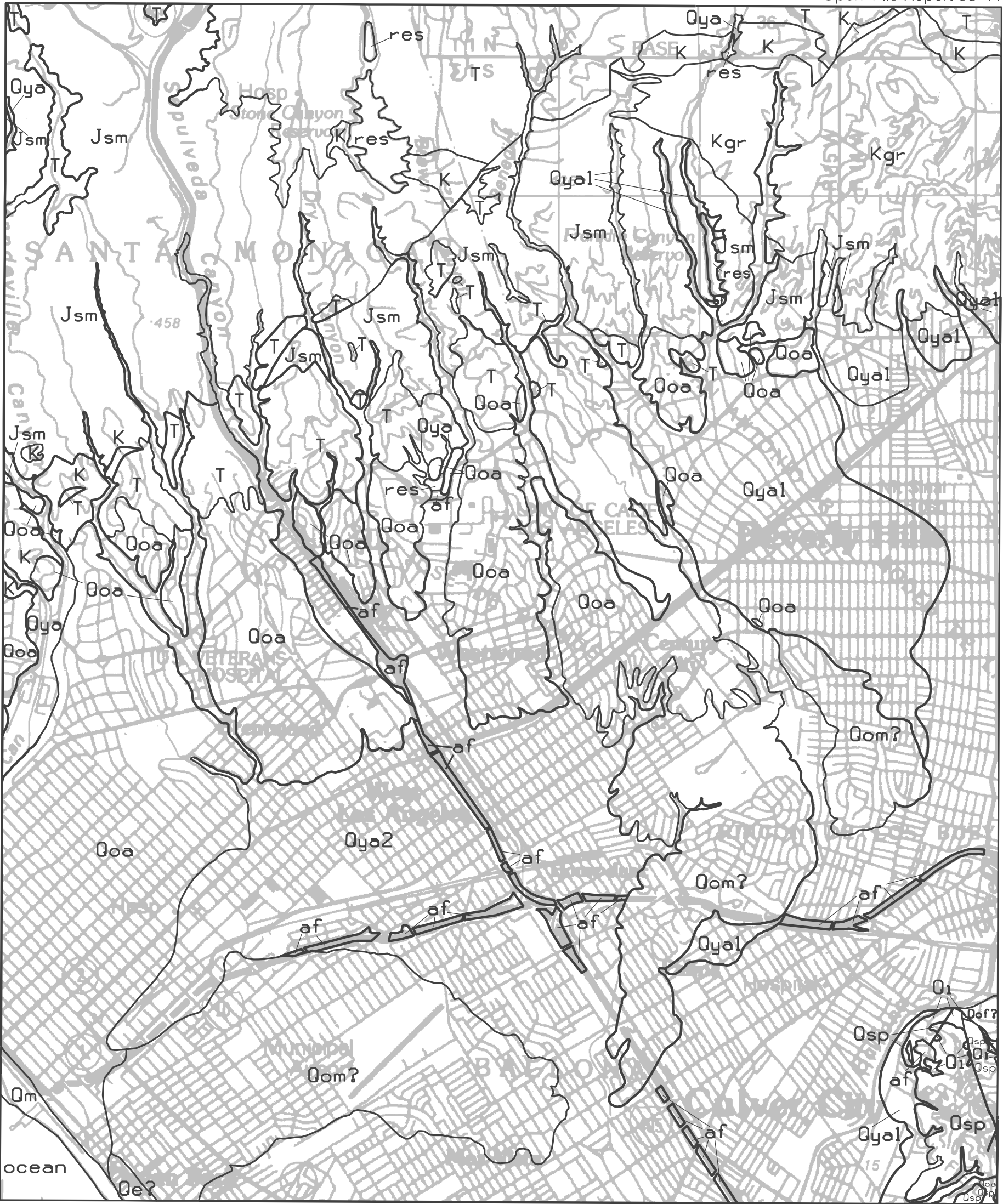
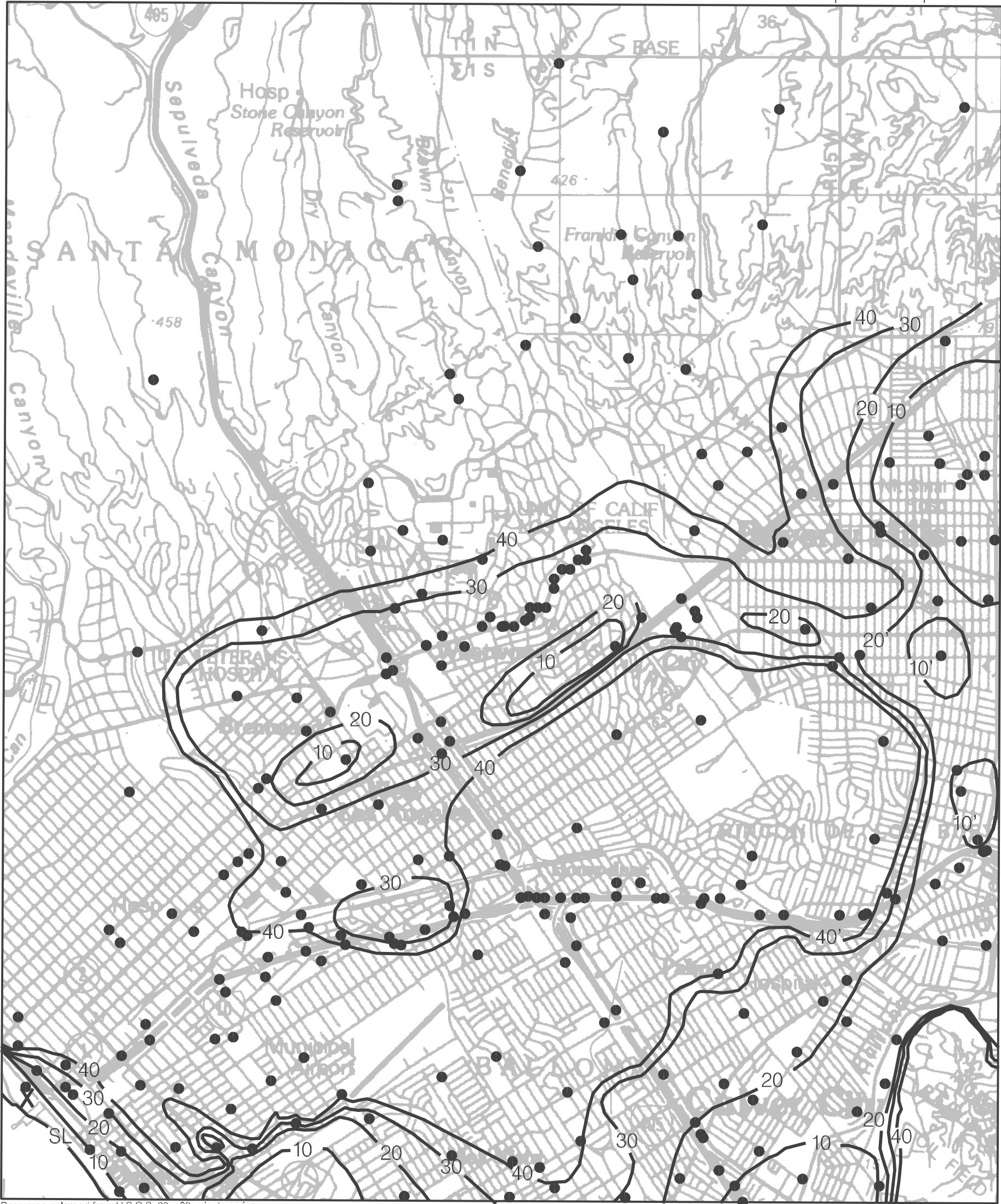


Plate 1.1 Quaternary Geologic Map of the Beverly Hills Quadrangle.
See Geologic Conditions section in report for descriptions of the units.
Pre-Quaternary rocks include:
Jsm = Jurassic Santa Monica Slate
K = Cretaceous sedimentary rocks
Kgr = Cretaceous granitic rocks
T = Tertiary rocks
res = reservoir.





Base map enlarged from U.S.G.S. 30 x 60-minute series

Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Beverly Hills Quadrangle.

● Borehole Site — 30 — Depth to ground water in feet

X Site of historical earthquake-generated liquefaction. See "Areas of Past Liquefaction" discussion in text.

ONE MILE
SCALE



Base map enlarged from U.S.G.S. 30 x 60-minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, Beverly Hills Quadrangle.

- shear test sample location
- landslide
- areas of significant grading

ONE MILE
SCALE